

**Wastewater Management Validation and Design Committee**  
**P. R. Ammann – Working Document**  
**Originated 15 October 2008**

**Caveat: This document is not final or complete and is not intended to be used for any purpose other than to facilitate further discussion.**

**Subject: Summary Chapter IV (Watershed Nitrogen Loading)**

The Massachusetts Estuaries Project - Linked Watershed-Embayment Model uses estimated quantities of nitrogen from multiple sources in each of many watersheds.

**Key Issues:**

1. The quantities of freshwater flow from precipitation and town water use into ponds and embayments have been estimated by groundwater flow measurements and metered water use.
2. The quantities of several sources of nitrogen migration into groundwater, and hence into either freshwater ponds or into estuaries and embayments, have been estimated.
3. The benthic flux generation during summer months have been determined by laboratory measurements; supporting reports and data are not available.

**Tasks to Be Undertaken to Address the Key Issues:**

- Task 1.** Conduct a critical review of the methodologies and sources of information for the several sources of nitrogen that flow into the Pleasant Bay System:
- a. The methodology and assumptions used to calculate natural background sources;
  - b. The methodology, calculations and assumptions for determining the quantities of nitrogen that derive from fertilizer and other soil applications, and roof and road runoff from precipitation;
  - c. The methodology, calculations and assumptions for determining the quantities of nitrogen that are produced by septic systems;
  - d. The estimated quantities of nitrogen produced by direct precipitation into ponds, lakes, and the embayments and estuaries;
  - e. The methodology, calculations and assumptions for determining the quantities of nitrogen generated by sediment in the bottom of ponds, embayments and estuaries.

**Task 2.** Select two or three representative watersheds to validate the calculations and estimates that have been used by SMAST in the Linked-Model to determine the TMDLs for the Pleasant Bay System.

**Task 3.** Obtain the reports and raw data on the benthic flux measurements from SMAST and conduct an independent review of the calculations and the results.

The purpose of conducting these tasks is to identify any significant problems or gaps in the nitrogen inputs to the linked Model.

**Expertise and Experience Required to Complete the Tasks:**

1. Work to be conducted by the WMV&DC and local assistance.

**APPENDIX**

## **Commentary:**

### Natural Background

The Pleasant Bay Report includes a source of nitrogen in groundwater or surface runoff that derives from natural organic decomposition. The Report assumes that this source is based on a forested area with no anthropogenic [man-made] sources.<sup>1</sup> This source is not described in detail and there does not appear to be any information on the chemical form of this nitrogen source. Further, it appears that this source is not included in the calculations of nitrogen release into ponds, embayments or estuaries.

### Natural Precipitation Recharge.

SMAST assumed that the average annual precipitation is 44 inches per year. Of this amount, 27.25 inches reaches the groundwater under land surfaces; the remainder is evaporated, primarily during warm summer months. These data are used to estimate the rate of fresh water recharge into the groundwater, or in estimating the roof and road runoff. This information is used to calculate roof and road runoff and direct precipitation of acid rain. There are other sources with different estimates of precipitation and trans-evaporattion.

### Land Use Load

This group consists of several sources as described below.

#### Lawn Fertilizers.

Fertilizers consist of nitrogen which, when applied to lawns, farms, golf courses and any other land surfaces, dissolves. Theoretically, surface plantings take up the nitrogen, but in actual practice, some fraction reaches the groundwater. The SMAST model assumes that 15 pounds (6.44 kg) is applied to the average lawn annually. Further, fertilizer is applied to only 50 percent of residential lawns, and 20 percent of the applied nitrogen reaches the groundwater. With an application rate of only 72 percent of 15 pounds (i. e., 10.8 pounds), 1.08 pounds (0.49 kg) reaches the groundwater<sup>2</sup>. The applications of nitrogen fertilizer to cranberry bogs and golf courses are different, as shown in the table cited.

A more recent report by Petrovic suggests that only 10 percent of nitrogen applied as fertilizer reports to groundwater.

#### Roof Runoff.

Precipitation, in the form of rain or snow, contains small quantities of acid rain in the form of nitrate or nitrite. SMAST assumed that the concentration of nitrogen in runoff from building roofs is 0.75 mg/liter. Further it is assumed that 90 percent of the runoff is carried into dry wells where it is discharged directly into the groundwater. Ninety percent of the nitrogen contained in the precipitation is assumed to reach the groundwater.<sup>3</sup> There are several studies cited by the Cape Cod Commission of the nitrogen content of roof and road runoff with widely different measurements.

#### Road Runoff.

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<sup>1</sup> Pleasant Bay Report, SMAST, May, 2006, page ES-11, Table ES-1a, Footnote 1.

<sup>2</sup> Pleasant Bay Report, SMAST, May 2006, page 36, Table IV-4.

<sup>3</sup> Pleasant Bay Report, SMAST, May 2006,

Precipitation onto road and parking surfaces is assumed to collect in catch-basins from which it is discharged directly into groundwater; 90 percent of the nitrogen is assumed to reach the groundwater. SMAST assumed that the road runoff contains 1.5 mg/liter of nitrogen, or twice the concentration from roofs. No explanation is given. There are several studies cited by the Cape Cod Commission of the nitrogen content of roof and road runoff with widely different measurements.

### Septic Systems.

To estimate the contribution by residential and commercial septic systems of nitrogen into fresh and saltwater bodies, it appears that SMAST used local property water metering data [provided by the Orleans water department for 12 months during the years 2002 - 2003] and an estimate of 64 gallons consumption of water per day per person. By dividing the metered annual water use by 64 gallons per day per person, an estimate was made of the number of residents in each property per year.

The calculations further assumed that 90 percent of that amount [*this number might be 85 percent, but documentation is lacking*], or 57.6 gallons per day per person reported to the septic system with nitrogen concentration of 35 mg/liter [35 parts per million]. It appears that this yielded the total amount of nitrogen transported from each property to the groundwater in 2003. SMAST calculated that there are about 2.05 persons per residence in Orleans.<sup>4</sup>

Published information indicates that the average per capita loads is on the order of 1.9 to 2.1 kilograms of nitrogen per person per year, with an average of 2.1 kg/yr/person.<sup>5</sup>

Orleans was divided into a number of watersheds from which groundwater flows entirely into one of the freshwater ponds or into one of the many embayments in the Pleasant Bay System. These watersheds were defined by the USGS and SMAST based on well measurements on groundwater levels.

The Cape Cod Commission used maps to determine which properties in Orleans were located within each of the watersheds. The Cape Cod Commission then constructed large databases with information on each property within each watershed and calculated the contributions of nitrogen from all sources into the groundwater and surface water runoff.

For each residential property, the nitrogen discharge to the groundwater was calculated from 90 percent of the metered water use and the assumed concentration of nitrogen in the typical septic effluent and a 25 percent reduction of nitrogen in the Title V title system.

Using the metered water use data, the database calculates the number of people living in a residential property. However, these calculations do not agree, in many instances, with data on occupancy obtained from the annual census. A question arises as to whether the use of metered water is a reasonably good measure of the contributions of nitrogen into the groundwater in local watersheds.

### Atmospheric Deposition [Acid Rain].

Acid rain is a direct contributor of nitrogen to freshwater ponds and to embayments and Pleasant Bay. SMAST assumed that there is an average 44 inches of precipitation in Orleans and that the collected water contains 0.75 mg/liter [0.75 parts per million] of contained nitrogen.

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<sup>4</sup> Pleasant Bay Report, May 2006, page 33.

<sup>5</sup> Pleasant Bay Report, May 2006, page 30.

## Benthic Flux.

Summary data on the nitrogen inputs into the Pleasant Bay System shows that benthic flux is a major contributor compared to other sources. Benthic flux is the contribution from sediments that lie at the bottom of water bodies. It is a complicated source to define in that it represents nitrogen that is supplied by the decay of marine organisms that die in the sediment as well as nitrogen that is absorbed from the water column above during cold winter months and is released to the water column during the warm summer months. It also includes nitrogen that is "recycled" by the summer growth of phytoplankton, sea lettuce, etc., which dies, and then in subsequent summer months is a contributor of nitrogen into the water column.

There are no direct measurements of nitrogen for the bottom of water bodies. SMAST collected core samples, approximately 25 cm (approximately 10 inches) in diameter, and brought the samples to their laboratory where the rates of leaching of nitrogen into water were measured under controlled conditions. The rates were converted into units of milligrams of nitrogen per square meter of surface area per day. The Pleasant Bay Report contains only a brief description of the procedure; ***none of the data are available for independent analysis.***

## Reviewer Questions and Comments

**IV.2.2 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge from Pilgrim Lake to Kescayo Gansett (Lonnies) Pond – Upper Pleasant Bay** p 50 ¶ 3 “The annual freshwater flow record for the herring brook measured by the MEP (Table IV-8), was compared to the long-term average flows determined by the USGS modeling effort (Table III-1). The measured freshwater discharge from the herring brook was 8% of the long term average modeled flows. Therefore, the watershed and river datasets appear to be in balance.”  
*Should read “was **within** 8%”.*

**IV.2.2 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge from Pilgrim Lake to Kescayo Gansett (Lonnies) Pond – Upper Pleasant Bay** p 50 ¶ 4 and

**IV.2.3 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream Discharge from Cranberry Bog to Paw Wah Pond – Upper Pleasant Bay** p 55 ¶ 1  
*In both cases....” nitrate was not the predominant form of nitrogen (12%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the upgradient cranberry bog/pond and to the river was almost completely taken up by plants within the pond, bog or creek ecosystems. .... the low concentration of inorganic nitrogen and its small proportion relative to the total nitrogen pool suggests that nitrogen cycling in the upgradient systems is converting inorganic nitrogen to organic forms increasing the potential for removal prior to discharge.”*

*Nitrogen attenuation by the bog/pond and creek/river systems was 60% to 70% of the upper watershed loads.*

**IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS** p 25 ¶ 1 Sediment nitrogen recycling results primarily from the settling and decay of phytoplankton and macroalgae (and eelgrass when present). During decay, organic nitrogen is transformed to inorganic forms, which may be released to the overlying waters or lost to denitrification within the sediments. Burial of nitrogen is generally small relative to the amount cycled. Sediment nitrogen regeneration can be a seasonally important source of nitrogen to embayment waters and leads to errors in predicting water quality if it is not included in determination of summertime nitrogen load.

*Seems important to understand what mechanisms are involved, how this impacts the nitrogen mass balance and the ‘seasonal’ aspect.*

*Mass of Nitrogen from decay of plant matter? kg/acre/year?*

*Where does it go? When? How?*

*What is the specific (step by step detail) analytical procedure used?*

*Is there a standard analysis procedure in Standard Methods for Water and Wastewater Analysis (includes sediment analysis)?*

*Is there a copy of Standard Methods available in town? (none in library although it is available in the reference section of CC Community College). Should we have a copy?*

#### **IV.3 BENTHIC REGENERATION OF NITROGEN IN BOTTOM SEDIMENTS p 73**

*This section discusses sediment nitrogen recycling; same questions and issue pertain as noted above.*

#### **IV.3 BENTHIC REGENERATION OF NITROGEN IN BOTTOM SEDIMENTS**

##### **IV.3.1 Sediment-Watercolumn Exchange of Nitrogen p 73 ¶ 3**

“...as nitrogen enters the embayment from the surrounding watersheds it is predominantly in the bioavailable form nitrate. This nitrate and other bioavailable forms are rapidly taken up by phytoplankton for growth, i.e. it is converted from dissolved forms into phytoplankton “particles”. Most of these “particles” remain in the water column for sufficient time to be flushed out to a down gradient larger waterbody (like the Atlantic Ocean). However, some of these phytoplankton particles are grazed by zooplankton or filtered from the water by shellfish and other benthic animals and deposited on the bottom. Also, in longer residence time systems (greater than 8 days) these nitrogen rich particles may die and settle to the bottom. In both cases (grazing or senescence), a fraction of the phytoplankton with their associated nitrogen “load” become incorporated into the surficial sediments of the bays.

In general the fraction of the phytoplankton population which enters the surficial sediments of a shallow embayment: (1) increases with decreased hydrodynamic flushing, (2) increases in low velocity settings, (3) increases within enclosed tributary basins, particularly if they are deeper than the adjacent embayment (e.g. Paw Wah Pond, Kescayo Gansett Pond, Meetinghouse Pond, Areys Pond). To some extent, the settling characteristics can be evaluated by observation of the grain-size and organic content of sediments within an estuary.

Once organic particles become incorporated into surface sediments they are decomposed by the natural animal and microbial community. This process can take place both under oxic (oxygenated) or anoxic (no oxygen present) conditions. It is through the decay of the organic matter with its nitrogen content that bioavailable nitrogen is returned to the embayment water column for another round of uptake by phytoplankton. This recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems that have been investigated by SMAST and the MEP, recycled nitrogen can account for about one-third to one-half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings. Failure to account for this recycled nitrogen generally results in significant errors in determination of threshold nitrogen loadings. In addition, since the sites of recycling can be different from the sites of nitrogen entry from the watershed, both recycling and watershed data are needed to determine the best approaches for nitrogen mitigation.

*“Nitrogen recycling” is:*

- *Related to residence time in the sub-embayment. Less flushing potentially increasing recycling.*

*It seems that the same process occurs for all plant forms. Eelgrass also uses nitrates/nutrients and photosynthesis to grow and increase plant matter in the sub-embayment. Eelgrass dies seasonally and contributes to the available nitrogen in the body of water in future years.*

### **IV.3.3 Rates of Summer Nitrogen Regeneration from Sediments p 79 ¶ 2**

"The relative balance of nitrogen fluxes ("in" versus "out" of sediments) is dominated by the rate of particulate settling (in), the rate of denitrification of nitrate from overlying water (in), and regeneration (out). The rate of denitrification is controlled by the organic levels within the sediment (oxic/anoxic) and the concentration of nitrate in the overlying water. Organic rich sediment systems with high overlying nitrate frequently show large net nitrogen uptake throughout the summer months, even though organic nitrogen is being mineralized and released to the overlying water as well. The rate of nitrate uptake simply dominates the overall sediment nitrogen cycle.

In order to model the nitrogen distribution within an embayment it is important to be able to account for the net nitrogen flux from the sediments within each part of each system. This requires that an estimate of the particulate input and nitrate uptake be obtained for comparison to the rate of nitrogen release. Only sediments with a net release of nitrogen contribute a true additional nitrogen load to the overlying waters, while those with a net input to the sediments serve as an "in embayment" attenuation mechanism for nitrogen.

Overall, coastal sediments are not overlain by nitrate rich waters and the major nitrogen input is via phytoplankton grazing or direct settling. In these systems, on an annual basis, the amount of nitrogen input to sediments is generally higher than the amount of nitrogen release. This net sink results from the burial of reworked refractory organic compounds, sorption of inorganic nitrogen and some denitrification of produced inorganic nitrogen before it can "escape" to the overlying waters. However, this net sink evaluation of coastal sediments is based upon annual fluxes. If seasonality is taken into account, it is clear that sediments undergo periods of net input and net output. The net output is generally during warmer periods and the net input is during colder periods. The result can be an accumulation of nitrogen within late fall, winter, and early spring and a net release during summer. The conceptual model of this seasonality has the sediments acting as a battery with the flux balance controlled by temperature (Figure IV-20).

Unfortunately, the tendency for net release of nitrogen during warmer periods coincides with the periods of lowest nutrient related water quality within temperate embayments. This sediment nitrogen release is in part responsible for poor summer nutrient related health. Other major factors causing the seasonal water quality decline are the lower solubility of oxygen during summer, the higher oxygen demand by marine communities, and environmental conditions supportive of high phytoplankton growth rates."

*It seems that the relative magnitude of N loading to the sub-embayments is important. If septic nitrogen loading is eliminated or reduced, does it make the sub-embayment healthy again? Or, is the nitrogen accumulation in plants and animals and the impact of their life cycles on the nitrogen mass balance the problem? This is not a prejudgment of the facts; it is simply a question at this time.*

### **IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS p 29 ¶ 1**

*Wording seems vague as to how much detailed data on land use was available or employed vs. broad categorization of land use and estimates. How detailed (e.g. lot by lot) was the land use information and what is meant by pre-determined nitrogen loading rates? Do we want to do a detailed analysis and nitrogen mass balance for a specific sub-embayment and compare to the model results?*

### **IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS p 29 ¶ 3**

*Why was data collected only during summer months? Does this properly account for nitrogen transport and mass balance on year round basis?*

#### IV.1.2 Nitrogen Loading Input Factors Wastewater/Water Use p 32 ¶ 3

*A bit difficult to follow. Metered water use records are used as a proxy for occupancy rates and there from nitrogen loadings in watersheds. The report acknowledges that water use does not account for occupancy rates of dwelling in areas like Orleans where population varies by month of the year. However, references studies to support depending on water use.*

*Discusses "...MEP has derived a combined term the effective N Loading Coefficient (consumptive use times the nitrogen concentration) of 23.63 to convert water (per cubic meter) to nitrogen load (N grams)." Do we understand how this compensates for changes in occupancy rates?*

$m^3 = 1000$  liters

A = consumptive use in  $m^3$

B = N concentration mg/l (CCC uses 35)

N Load (grams) = 23.63AB?

*Where are the water use data and calculations that would help to understand this?*

*How do we go about testing/verifying the occupancy/water use/ N loading assumptions?  
Check specific embayments/sub-embayments?*

**The text is not clear.** The apparent source of the 23.63 is as follows:

*2.1 kg nitrogen per person per year, or*

*2,100,000 mg per person per year, or*

*5,753 mg per person per day [2,100,000 mg/person/year]/[365 days/year]*

*The CCC in Technical Bulletin 91-00, April 1992, states that the average concentration of nitrogen in wastewater is 35 mg/liter. This is equivalent to [35 mg/liter] \* [3.785 liters/gallon], or 132.475 mg/gallon.*

*At 35 mg/liter, then, the **daily water use** is [5,753 mg/day]/ [132.475 mg/gallon], or 43.43 gallons per day per person.*

*However, the Town of Orleans determined, from annual water usage in 2002 – 2003 and an estimate of the average annual population, that the annual water use was 64 gallons per day per person. Consequently, the concentration of nitrogen in septic wastewater is calculated as follows:*

$$[5,753 \text{ mg/day/person}] / [64 \text{ gallons/day/person} * 3.785 \text{ liters/gallon}] = \mathbf{23.75 \text{ mg/liter}}$$

{approximately **23.63 mg/liter**}

*Thus, the 23.63 mg/liter nitrogen concentration in wastewater is keyed to the water usage of exactly 64 gallons per day per person in Orleans.*

#### **Orleans Future:**

*The issue of occupancy rates brings to mind the question of what happens in 10 or 20 years with occupancy and build out. Perhaps this subject has been thoroughly dealt with by WMSC. If not, it seems to be worth raising.*

*We are looking at a project with a ~30 year horizon. What does the future population structure of Orleans look like? Knowing the current nitrogen loading and mass balance is important. How do we think it will change over 20-30 years?*

*Is the trend to more 'second' homes that are occupied for only 3-5 months per year? Or, will the second homes of today be occupied year around as the baby boomers retire? If the baby*

*boomers retire here, what does that mean with regard to occupancy? Year around? Summer, with winter residence elsewhere?*

*What infrastructure is needed to support that population in terms of public and, importantly, retail shops and services?*

*How does this impact the nitrogen loading of the embayments in 20 years?*